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Investigating the Austempering Parameters of Ductile Iron by Magnetic Barkhausen Noise Technique

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Abstract

The optimum mechanical properties for austempered ductile iron (ADI) can be achieved if the heat treatment is conducted in a restricted time and temperature frame called the "processing window". In this study MBN response and variations in microstructure and mechanical properties of ADI have been investigated. In the experiments, unalloyed ductile iron samples have been austenitized, and then, transferred to a salt bath for austempering for various times. It has been observed that there is a very good correlation between MBN response and variations in microstructure and mechanical properties and the processing windows of ADI can be estimated by nondestructive MBN method.

Keywords: Austempered Ductile Iron; Material properties; Magnetic Barkhausen Noise.

1. Introduction

Ductile iron has commercially replaced as-cast and forged steels in the lower strength region, now ADI is finding applications in the higher strength regions. In addition ADI weights only 2.4 times more than aluminum and is 2.3 times stiffer. ADI is also 10% less dense than steel. Therefore, when one compares the relative weight per unit of yield strength of ADI with that of various aluminums and steels it is easy to the engineering and design advantages inherent in ADI [1]. Mechanical properties of ADI depend on the austempered microstructure [2-5] which, in turn, is a function of austempering time and temperature. The optimum mechanical properties for austempered ductile iron can be achieved if the heat treatment is conducted in a restricted time and temperature frame called the "processing window" [6]. Determining the processing window by experiments is time consuming and expensive, and hence it is attractive to utilize non-destructive techniques. The purpose of this study is to non-destructively quantify the volume fraction of phases, to estimate the relationships between structure and properties, and to determine the processing windows of ADIs by Magnetic Barkhausen Noise (MBN) method.

2. Experimental study

The ductile iron (Fe-3.50C-2.63Si-0.318Mn- 0.019P-0.009S-0.047Mg in wt %) was produced in the form of Y-blocks by induction melting. The specimens machined from the bottom section of the blocks were annealed at 900°C for 90 minutes, then, were rapidly transferred to a salt bath at 365°C, and held for various durations (30, 60, 120 and 180 min).

Specimens were prepared standard metallographic techniques and etched with 2% Nital, then microstructures were examined by optical microscopy. The relative amounts of the high carbon austenite and ferrite volume fractions were measured by X-Ray diffractometry. Diffraction profiles for (220) peak of austenite, and (211) and (311) peaks of ferrite in the range of 40-100° were obtained on a Brucer D8 X-ray diffractometer at 40 kV and 20 mA using monochromated Cu-Kα radiation. The volume fraction of martensite was determined by point counting on etched metallographic sections. Tensile test specimens were machined from the bottom sections of Y blocks by removing decarburized layers from the surface. Tension tests were carried out using a Dartec machine. The average values were calculated by considering the results of at least five tests. Hardness measurements were made using an Instron Wolpert Diatestor 7551 tester. At least five indents were made at each location and average values were taken.

MBN measurements were carried out using a commercial system (Stress Tech μscan 500-2). A cyclic magnetic field was induced in a small volume of the specimen with a coil, energized with alternating current. The proper contact of the sensor was ensured by clips applying the same contact pressure to each sample. The measurements were carried out at the excitation magnetic field of 125 Hz. A smooth sine-waveform of magnetic excitation was achieved by setting both signal amplification and gain to 20 dB. Two parameters from the MBN data (MBN fingerprint) were analyzed: the height (relative r.m.s. voltage) and the position (relative magnetic excitation field) of the MBN peak.

3. Results and discussion

During austempering, ADI undergoes a two stage transformation reaction. In the first stage the parent austenite decomposes into bainitic ferrite α_b and high carbon austenite γ_{hc} (retained austenite). During the second stage, this supersaturated high carbon austenite further decomposes into bainitic ferrite and carbides. The desired microstructure of the austempered ductile iron is bainitic ferrite and high carbon austenite, commonly called ausferrite. This desired ausferrite microstructure is obtained at the austempering time interval (called processing window) between end of stage-I and at the beginning of stage-II reactions. The ductile cast iron with this desired ausferrite microstructure displays optimum mechanical properties [7-13]. The microstructure of the as-cast specimen consists of ferrite grains surrounding the graphite nodules (Fig. 1). An example of the microstructural changes as a function of time observed during austempering is given in Fig. 2.

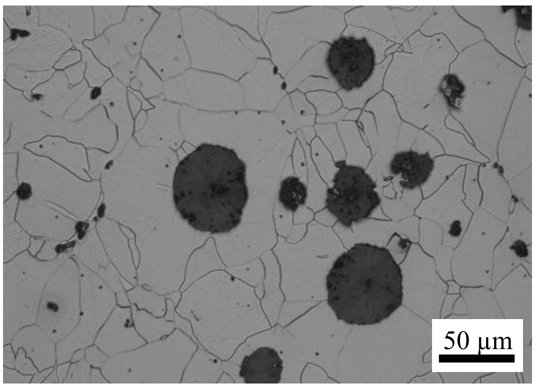

Figure 1. Microstructure of the as-cast ductile iron.

Austempering for short time, after austenitising at 900°C, produced long continuous martensite paths in the eutectic cell boundaries (Fig. 2.a and 2.b). As the austempering time increases up to 30 min, the amount of martensite derived from low carbon austenite decreases. With further increasing austempering time and stage-I reaction approaching completion, the amount of MVF decreases and bainitic ferrite and high carbon austenite content increases (Table 1). In all series increasing the austempering time caused bainitic ferrite and high carbon austenite to displace martensite. After approximately 120 minute austempering, martensite almost disappeared. Between 120-180 minute austempering, the volume fractions of bainitic ferrite and high carbon austenite stay almost unchanged. The results show that an austempering time between 60 and 130 minutes at 365°C is well within the process window.

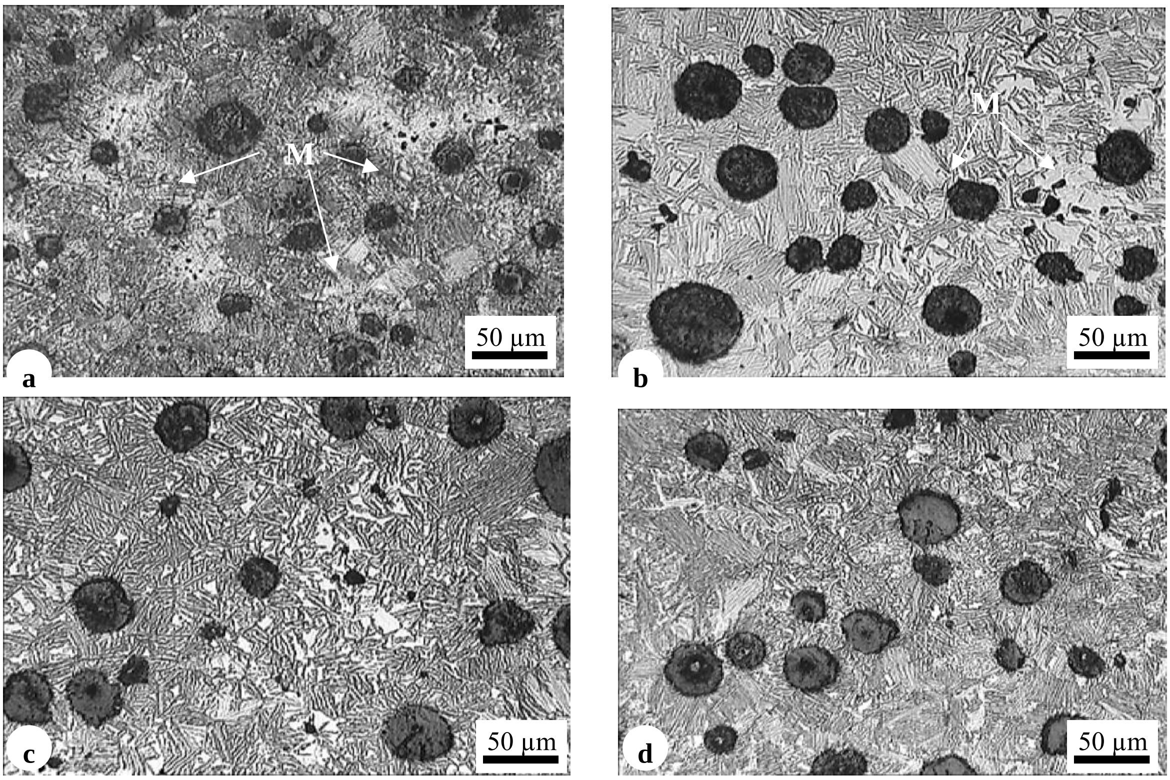

Figure 2. Microstructures of the specimens at various austempering times; (a) 30 min, (b) 60 min, (c) 120 min and (d) 180 min. (M: Martensite).

The average values of yield and tensile strengths and total elongation of the specimens are also given in Table 1. The relatively low strength values at short austempering durations are attributed to the brittleness associated with martensite which forms in low carbon, unreacted austenite areas during cooling from austempering temperature to room temperature. Total elongation of samples increased with increasing austempering time causing the more ductile ausferritic structure to displace hard martensite.

On MBN fingerprint, the peak position indicates the magnetic field at which the peak value of the MBN signal is located. Ferrite and pearlite have a strong Barkhausen activity located at a low magnetic field, whereas a martensite microstructure, which is classified as hard magnetic phase, has a low Barkhausen emission located at a high field [14-19]. The as-cast ductile iron consisting of proeutectoid ferrite matrix surrounding the graphite nodules gives the highest MBN peak amplitude, indicating that there is a wider range of jump sizes for domain walls. Since nodularity and volume fraction of the graphite are identical for all the samples, their effect is negligible.

Table 1. Results of phase proportions and tensile tests

Specimen Code	Austempering Time (minute)	Retained Austenite (Vol.-%)	Bainitic Ferrite (Vol.-%)	Martensite (Vol.-%)	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)	Hardness (HV 5)
As-cast	-	-	89.8*	-	262	397	27.7	175
C900	30	19.3	28.1	52.6	816	1111	3	345
	60	28.5	37.9	33.6	784	1090	10.6	324
	120	39.3	55.2	5.5	778	1086	12.1	302
	180	37.8	62.2	0	810	1105	10	315

* Proeutectoid Ferrite (vol.-%)

As austempering duration increases from 30 to 180 minutes, the peak position range varies between 15% and 31% whereas the peak height varies between 27% and 12.5%. For the durations between 60 and 120 minutes, peak height goes to a minimum while the peak position makes a maximum. This range also defines the optimum strength and ductility values. Some differences in the peak field position, r.m.s. voltage and magnetic parameter have been observed (Fig.3). When austempering temperature is increased, MBN amplitude generally increases, although the retained austenite content is higher for upper bainite than for lower bainite. This means that the major roles are then played by the tetragonality and morphology of the bainitic ferrite. The decrease of MBN amplitude when austenitization temperature is increased is associated with a decrease in the vol. fraction of bainitic-ferrite. MBN peak position and volume fraction of retained austenite is very sensitive to austempering time (Fig. 4), and there is a direct relationship between peak position and total elongation (Fig. 5). The results are in agreement with literature [20].

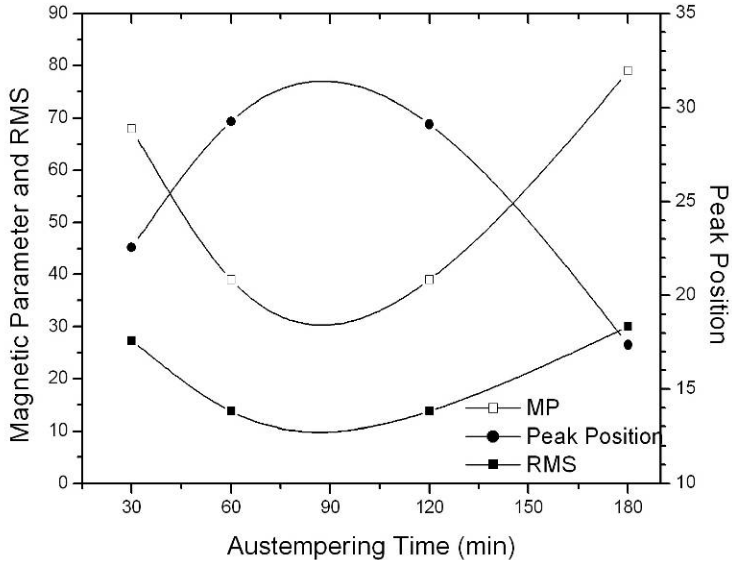

Figure 3. Variation of MBN parameters with austempering time

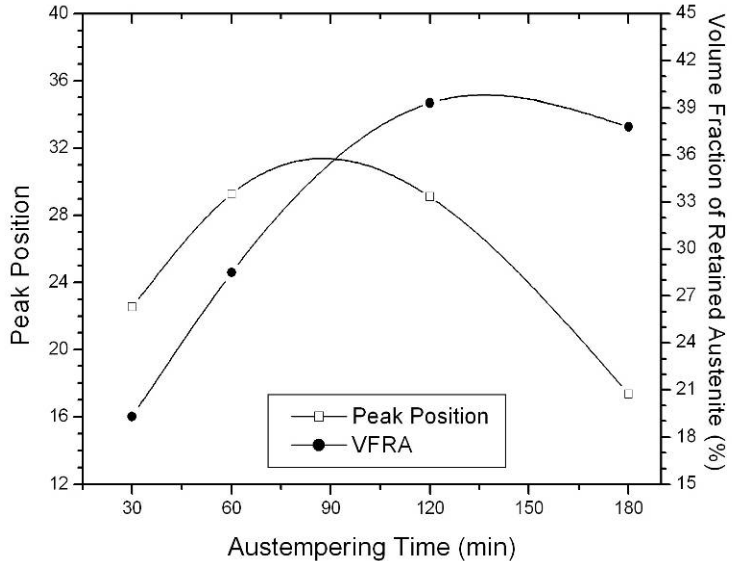

Figure 4. Variation of MBN peak position and vol. fraction of retained austenite (VFRA) with austempering time.

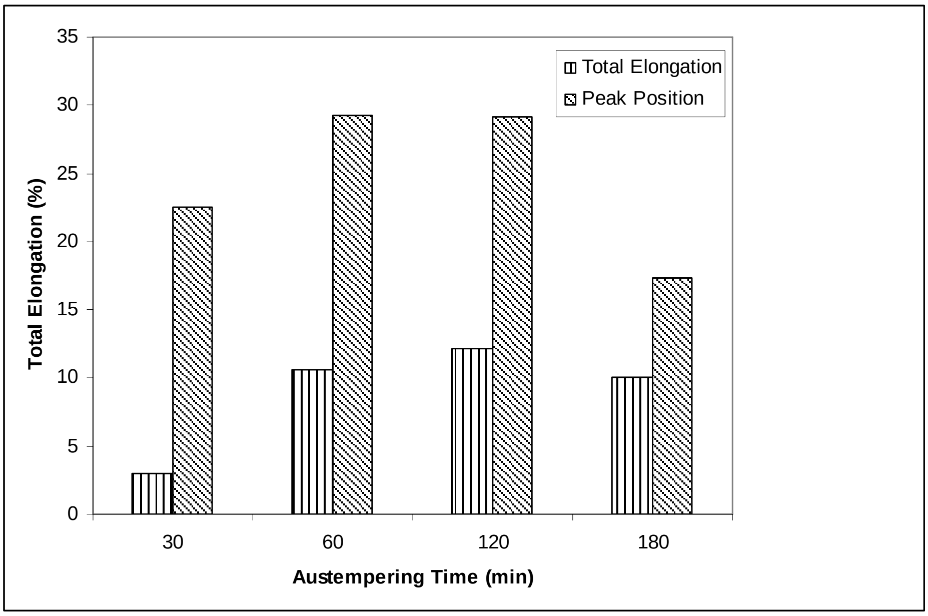

Figure 5. Variation of total elongation and peak position with austempering time

4. Conclusion

MBN measurements are sensitive to the fine evolutions of the austempering stages of austempered ductile iron. Martensite volume fraction gradually decreases and finally disappears with increasing the austempering time while the transformed austenite content decreases and acicular ferrite contents increases. By measuring the MBN parameters such as, the height and the position of MBN peak, the changes in the microstructure and corresponding variations in yield and tensile strengths, and total elongation can be estimated non-destructively.

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